UPDATED LIMITS ON VISIBLY AND INVISIBLY DECAYING HIGGS BOSONS FROM LEP

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The problem of mass generation remains one of the main puzzles in particle physics today. In the standard model all masses arise as a result of the spontaneous breaking of SU(2)⊗U(1) the gauge symmetry. This implies the existence of an elementary Higgs boson not yet found. Recently the LEP experiments on e^+e^- collisions around the Z peak have placed important restrictions on the Higgs boson mass $m_{H_{SM}} \gtrsim 60$GeV.

There are many reasons to think that there may exist additional Higgs bosons in nature. One such extension of the minimal standard model is provided by supersymmetry and the desire to tackle the hierarchy problem [1]. Another reason is neutrino physics. Indeed, there are many extensions of the minimal standard model which induce neutrino masses either at the tree level or radiatively through an enlargement in the Higgs sector [2].

In many of these extensions one has the possibility that the Higgs boson may decay into invisible particles, such as $H \to \chi\chi$ where χ is the lightest neutralino in supersymmetry, possible when $2m_\chi < M_H$.

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Amongst the extensions of the standard model which have been suggested to generate neutrino masses, the majoron models are particularly interesting and have been widely discussed [2]. The majoron is a Goldstone boson associated with the spontaneous breaking of the lepton number. Astrophysical arguments based from stellar cooling rates constrain its couplings to the charged fermions [3], while the LEP measurements of the invisible Z width restrict the majoron couplings to the gauge bosons in an important way. In particular, models where the majoron is not a singlet [4] under the SU(2)⊗U(1) symmetry are now excluded [5].

There is, however, a wide class of models [6], motivated by neutrino physics, which are characterized by the spontaneous violation of a global $U(1)$ lepton number symmetry by an SU(2)⊗U(1) singlet vacuum expectation value $\langle\sigma\rangle$ [7]. These models may naturally explain the neutrino masses required by astrophysical and cosmological observations [8].

Another example is provided by supersymmetric extensions of the standard model where R parity is spontaneously violated [9].

In all these extensions of the minimal standard model the global $U(1)$ lepton number symmetry is spontaneously violated close to the electroweak scale. Such a low scale for the lepton number violation is preferred since, in these models, $m_\nu \to 0$ as $\langle\sigma\rangle \to 0$. As a result, a relatively low value of $\langle\sigma\rangle$ is required in order to obtain naturally small neutrino masses [6].

In any model with a spontaneous violation of a global $U(1)$ symmetry around the weak scale (or below) the corresponding Goldstone boson has significant couplings to the Higgs bosons, even if its other couplings are suppressed. This implies that the Higgs boson can decay with a substantial branching ratio into the invisible mode [6, 10, 11] $h \to J + J$ where J denotes the majoron.

Such an invisible Higgs decay would lead to events with large missing energy that could be observable at LEP and affect the corresponding Higgs mass bounds. In order to do this we determine the Higgs boson production and visible and invisible decay rates, which involves three independent parameters: the Higgs boson mass M_H, its coupling strength to the Z, normalized by that of the standard model, we call this factor ϵ^2, and the invisible Higgs boson decay branching ratio.

We have used the same method as described in [16], in order to deduce the regions in the parameter space of the model that can be ruled out already. The procedure was the following: In each case we have allowed the Higgs boson to decay into invisible channels with an arbitrary branching ratio between 0 and 1, and kept the weakest limit. In order to do this we have first considered the two extreme limits where the Higgs boson decays 100% visibly or invisibly; we obtained the absolute bound on the coupling ZZh (ϵ^2) as a function of m_H. The analysis was made considering the two differents signals given in the Higgs boson decay: the invisible case and the visible one.

For the invisible case, namely: $Z \to HZ^*$, $H \to$ invisible, $Z \to q\bar{q}$, we used directly the results presented by the Aleph Collaboration in reference [18], in which they set a limit on the maximum allowed coupling of the Higgs to the Z^0 as a function of its mass.

For the visible case: $Z \to HZ^*$, $H \to q\bar{q}$, $Z \to \nu\nu$ or ll where we directly applied the limits from the standard searches, using results from all experiments [17, 18, 19, 20]. In these case the background events were considered where they existed. For all values of the Higgs mass, we found that the weakest limit was obtained in the case of 100% standard decays, since in this channel it is not possible to tag the events in which the Z^0 decays hadronically due to the large background from normal processes.

As an illustration we show in Figure 1 the exclusion contours in the plane ϵ^2 vs. $BR(H \to \text{visible})$ for the particular choice for the Higgs mass $M_H = 50$ GeV. The two curves corresponding to the searches for visible and invisible decays are combined to give the final bound; values of ϵ^2 above 0.1 are ruled out independently of the value of $BR(H \to \text{visible})$. The solid line in Figure 2 shows the region in the ϵ^2 vs. M_H that can be excluded by the present LEP analyses, independent of the mode of Higgs decay, visible or invisible. An analysis on invisible higgs bosons can also be found in [12].

We have also estimated the additional range of parameters that can be covered by LEPII. We assumed that the total luminosity collected will be 500 pb^{-1}, and give the results for two values of the centre-of-mass energy: 175 GeV and 190 GeV. Our results on the visible decays of the Higgs are based on the study of efficiencies and backgrounds in the search for the Standard Model Higgs described in reference [13]. For the invisible decays of the Higgs we considered only the channel HZ with $Z \to e^+e^-$ or $Z \to \mu^+\mu^-$, giving a signature of two leptons plus missing transverse momentum. The requirement that the invariant mass of the two leptons must be close to the Z mass can kill most of the background from WW and $\gamma\gamma$ events; the background from ZZ events with one of the Z decaying to neutrinos is small and the measurement of the mass recoiling against the two leptons allows to further reduce it, at least for M_H not too close to M_Z. Hadronic decays of the Z were not considered, since the background from WW and $We\nu$ events is very large, and b-tagging is much less useful than in the search for ZH_{SM} with $Z \to \nu\bar{\nu}$, since the $Zb\bar{b}$ branching ratio is much smaller than $Hb\bar{b}$ in the standard model. The dashed and dotted curves on figure 2 show the exclusion contours in the ϵ^2 vs. M_H plane that can be explored at LEPII, for the given centre-of-mass energies. Again, these contours are valid irrespective of whether the Higgs decays visibly, as in the standard model, or invisibly. The possibility of invisible Higgs decay is also very interesting from the point of view of a linear e^+e^- collider at higher energy [15].
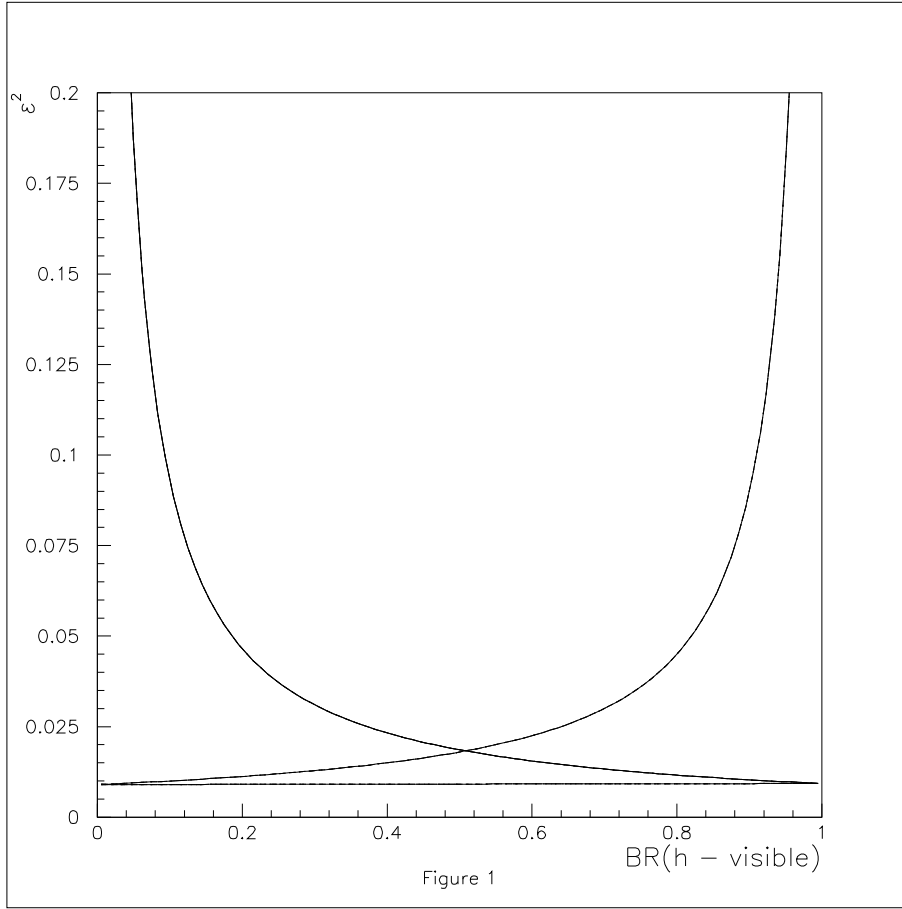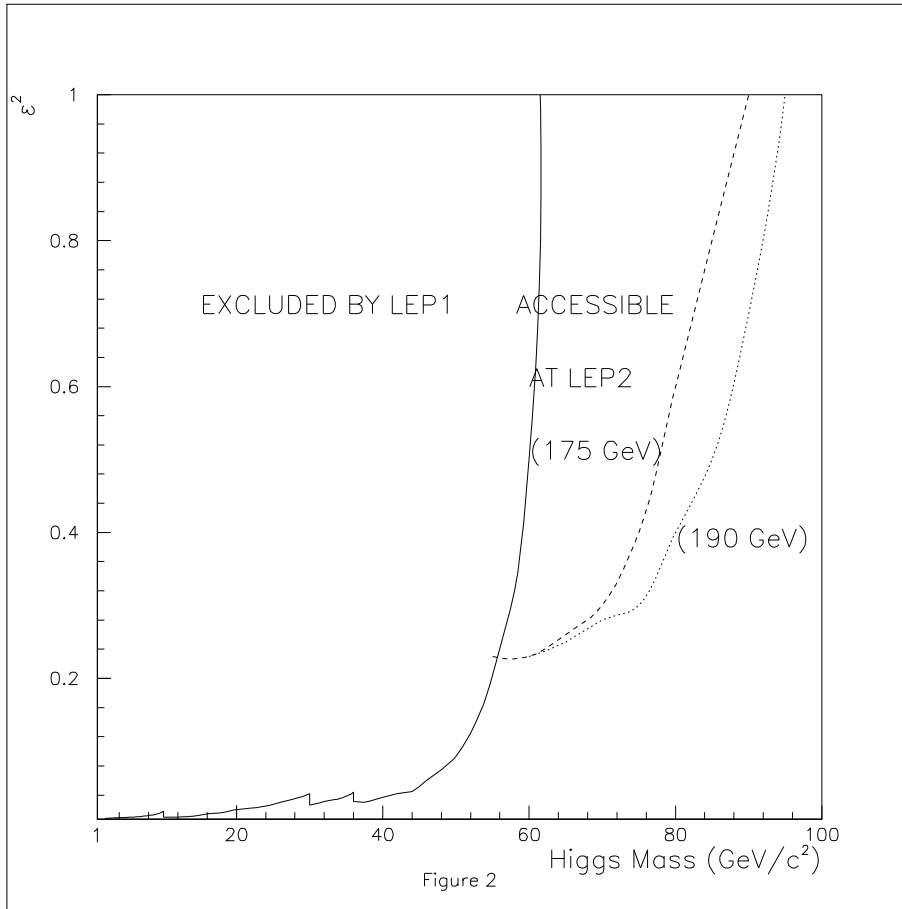
Figure Captions

Figure 1

Figure 1 shows the exclusion contours in the plane ϵ^2 vs. $BR(H \to \text{visible})$ for the particular choice $m_H = 50$ GeV. The two curves corresponding to the searches for visible (curve A) and invisible (curve B) decays are combined to give the final bound, which holds irrespective of the value of $BR(H \to \text{visible})$.

Figure 2

The solid curve shows the region in the ϵ^2 vs. m_H that can be excluded by the present LEP analyses. The dashed and dotted curves on figure 2 show the exclusion contours in the ϵ^2 vs m_H plane that can be explored at LEPII, for the given centre-of-mass energies.

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